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(71) Applicant: THE BABCOCK & WILCOX COMPANY
New Orleans, Louisiana 70160-0035 (US)

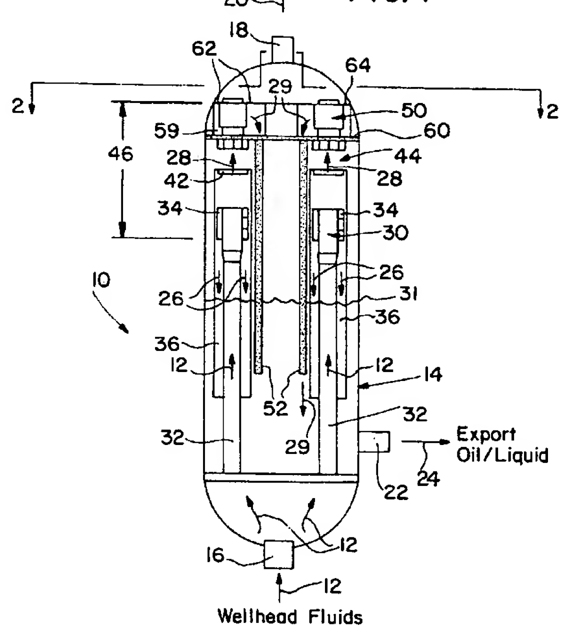
(72) Inventors:
- Prueter, William Paul
Alliance, Ohio 44601 (US)
- Birmingham, Daniel P.
North Canton, Ohio 44721 (US)
- Reed, Matthew J.
Canton, Ohio 44709 (US)

(74) Representative: Pilch, Adam John Michael et al
D. YOUNG & CO.,
21 New Fetter Lane
London EC4A 1DA (GB)

(54) Separation of oil and gas phases in wellhead fluids

(57) A wellhead fluid mixture containing oil and gas phases obtained from hydrocarbon production systems is separated into its constituent parts by means of a pressure vessel (14) having an inlet (16) for entry of the wellhead fluid mixture (12) and an outlet (18) for exit of a separated gas referred to as export gas (20). A primary centrifugal separator (30) is provided in the pressure vessel (14) for centrifugally separating a first portion of the oil from the wellhead fluid mixture (12) to produce a wet gas containing some remaining oil. A second centrifugal separator (50) is also provided in the vessel (14) and performs a second centrifugal separation operation on the wet gas to remove substantially all of the remaining oil from the wet gas to produce the export gas (20) which is conveyed out of the pressure vessel (14). The oil and remaining oil separated from the wellhead fluid mixture (12) is conveyed from the pressure vessel (14) via another outlet (22).

FIG. I



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Description

This invention relates in general to separation systems and, in particular, to methods and apparatus for separating a multiple phase mixture into separate vapour and liquid phases. The invention is particularly suited for applications involving the separation of oil and gas phases contained in wellhead fluids obtained from hydrocarbon production systems.

Most of the known gas/oil separation systems rely on natural or gravity separation which requires large vessels to achieve the desired separation performance. When natural separation is used in a relatively small vessel, the throughput or vapour flux of that system is significantly smaller when compared to other systems not relying on natural separation. An example of a system which apparently uses natural separation is described in US Patent No. US-A-4 982 794.

One known separation system is disclosed in UK Patent Application No. GB-A-2 203 062 which uses centrifugal separation for a primary separation stage and inertial separation (i.e., scrubbers) for a second stage of separation. Although this system most likely has higher separation capacities than a system relying on natural separation, it most likely has less capacity when compared to a system that could employ centrifugal separation for both stages.

Presently, there is no known gas/oil separation system or method for separating a multiple phase mixture of oil and gas into separate vapour and liquid phases utilizing single or multiple pairs of centrifugal force separators.

According to one aspect of the invention there is provided apparatus for the separation of oil and gas phases contained in well head fluids obtained from hydrocarbon production systems, the apparatus comprising:

a pressure vessel having a wellhead fluid inlet for entry of the wellhead fluids, a gas export outlet for exit of export gas separated therefrom and a liquid export outlet for exit of liquid separated therefrom;
first centrifugal separation means in the pressure vessel for centrifugally separating oil from the well head fluids to produce a wet gas containing some remaining oil; and
second centrifugal separation means in the pressure vessel for further centrifugally separating substantially all of the remaining oil from the wet gas to produce the export gas.

According to another aspect of the invention there is provided a method of separating a wellhead fluid mixture obtained from hydrocarbon production systems containing oil and gas phases into its constituent parts, the method comprising the steps of:

conveying the wellhead fluid mixture into a pressure vessel;
performing a first centrifugal separation of the oil from the wellhead fluid mixture to produce a wet gas containing some remaining oil; and
performing a second centrifugal separation of the wet gas to remove substantially all of the remaining oil from the wet gas to produce export gas.

The present invention is particularly suited for separating a wellhead fluid mixture containing oil and gas phases obtained from hydrocarbon production systems into its constituent parts. Embodiments of the present invention can be employed either topside or in subsea applications through the use of a compact and highly efficient separator arrangement.

More particularly, one embodiment of the present invention provides a separation apparatus which utilizes one or more curved-arm, centrifugal force, primary separator(s) and one or more cyclone, centrifugal force, secondary separator(s). Except for some changes made to the curved-arms, the primary separator is preferably similar to the separator described in US Patent No. US-A-4 648 890. The secondary separator is preferably similar to the separator described in US Patent No. US-A-3 324 634. The primary and secondary separators are always employed in pairs, and the combination of a centrifugal-type primary and secondary separator provides a compact and highly-efficient separator arrangement. The separator apparatus can be used in multiple pairs (two or more primary and two or more secondary separators) or in an apparatus having only a single primary and a single secondary separator. The multiple pair arrangement is typically used for topside applications while the single primary/single secondary separator arrangement is typically sufficient to satisfy most subsea applications.

Currently, topside or platform separation is normally performed using gravity separation which requires very large drum or pressure vessel volumes. Not only is the preferred embodiment of the present invention less costly to fabricate due to its smaller size than known separation devices, but the reduced size of the gas/oil separator thus requires less platform space, an economically attractive feature since the cost of platforms is directly related to the size of the vessels.

The preferred embodiment of the present invention also provides a unique and efficient compact apparatus for subsea separation of a gas and liquid mixture. In a subsea application, the present apparatus provides the most benefit for marginal field developments because without subsea separation, marginal fields may become economically unfeasible to operate.

As is well-known, subsea separation provides for the separation of vapour and liquid phases prior to transporting the fluids to a platform or production facility. Fewer technical challenges are involved with first separating the phases and then separately transporting them downstream as compared to transporting a multi-phase

mixture of gas and oil where slugging and hydrate formation issues are prevalent.

Presently, no other apparatus is known which provides a combination of centrifugal force primary and secondary separators having the compactness and high capacity separation efficiency of the present system.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 1 is a schematic sectional view illustrating a first embodiment of the present invention utilizing plural primary and plural secondary centrifugal separators;

Figure 2 is a cross-sectional view taken in the direction of arrows 2-2 in Figure 1;

Figure 3 is a schematic sectional view illustrating a second embodiment of the present invention utilizing single primary and single secondary centrifugal separators;

Figure 4 is a cross-sectional view taken in the direction of arrows 4-4 in Figure 3;

Figure 5 is a close-up, perspective view of a curved-arm, primary separator and a cyclone, secondary separator embodying the present invention; and

Figure 6 is a graph plotting test results for liquid flow versus vapour flow in a centrifugal separator arrangement embodying the present invention.

Referring to the drawings generally, wherein like numerals designate the same or functionally similar elements throughout the several drawings, and to Figure 1 in particular, one embodiment of the present invention provides a compact, high-efficiency, multiple pair, centrifugal gas/oil separator apparatus 10 for separating wellhead fluids 12 obtained from hydrocarbon production systems into separate oil and gas phases. As used herein, the term wellhead fluid means any two-phase mixture of oil and gas substantially in its natural state as extracted from the earth, or as transported from its extraction point to the gas/oil separator of the present system.

The gas/oil separator 10 comprises a drum or pressure vessel 14 having a wellhead fluid inlet 16 for providing the wellhead fluids 12 (typically crude oil and entrained gases) into the pressure vessel 14. A gas export outlet 18 is located at an end opposite the fluid inlet 16 of the pressure vessel 14 for conveying separated gases 20 from the pressure vessel 14. The pressure vessel 14 includes an oil/liquid export outlet 22 for conveying separated oil/liquids 24 from the pressure vessel 14. As shown in Figure 1, the pressure vessel 14 is oriented substantially vertically, with the wellhead fluid inlet 16 located generally at a lower end thereof, the gas export outlet 18 located at an upper end thereof, and the liquid export outlet 22 located at some intermediate location.

The oil/gas separator 10 employs multiple pairs of centrifugal force separators, in particular, one or more curved-arm, centrifugal force, primary separator(s) 30 and one or more cyclone, centrifugal force, secondary separator(s) 50. Since these primary and secondary separators 30, 50 are similar to those described in the aforementioned US Patent Nos. US-A-4 648 890 and US-A-3 324 634, the reader is referred to these references as needed for specific details. The primary and secondary separators 30, 50 are always employed in pairs, and the combination of a centrifugal-type primary and secondary separator provides a compact and highly-efficient separator arrangement. The wellhead fluids 12 are first acted upon by the curved-arm, centrifugal force, primary separator(s) 30 which perform a first centrifugal force separation of oil/liquids 26 from the two-phase wellhead fluids 12, producing a wet gas 28 with some remaining oil/liquid 29 therein. Then, the cyclone, centrifugal force, secondary separator(s) 50, located above and paired together with the curved-arm, centrifugal force, primary separator(s) 30, perform a second centrifugal force separation operation on the wet gas 28 leaving the primary separator(s) 30, from which a majority of the liquid has been removed, to remove as much of the remaining oil/liquid 29 from the wet gas 28 as possible.

Over 95 percent of the liquid in the wellhead fluids mixture 12 is separated therefrom by the primary separator(s) 30, and practically all of the remaining liquid in the wet gas 28 exiting the primary separator(s) 30 is removed by the secondary separators 50. Both the oil/liquid 26 removed by the primary separator 30 and the oil/liquid 29 removed by the secondary separator 50 are returned by gravity into a lower portion of the pressure vessel 14 forming a liquid inventory 31 therein. The high separation capacity of the primary and secondary separators 30, 50 allows for use of a single pair of primary and secondary separators if necessary, as shown in the embodiment of Figure 3. As mentioned earlier, the single primary/single secondary separator arrangement would typically be sufficient to satisfy most subsea applications and thus facilitates design optimization and confirmation testing at prototypic conditions described in greater detail later.

As illustrated in Figures 1 and 5, each curved-arm, centrifugal force, primary separator 30 comprises a riser tube 32 for conveying the well head fluids mixture 12 upwardly therethrough, four sets of multilayered curved-arms 34, and an outer can or return cylinder 36 surrounding the riser tube 32 and the curved-arms 34. As indicated earlier, the curved-arms 34 of the primary separator(s) 30 need not be of the re-entrant type disclosed in the aforementioned US Patent No. US-A-4 648 890; the curved-arms 34 may instead be just attached to the outside wall of the riser tube 32. The wellhead fluids mixture 12 enters at the bottom of the riser tube 32 and flows upwardly therethrough until reaching the vicinity of the curved-arms 34, where it exits the riser tube 32. The majority of the oil/liquid separation from the wellhead fluids

mixture 12 occurs as the mixture 12 flows through the curved-arms 34, the denser oil/liquid 26 in the mixture 12 tending towards the outer walls of the curved-arms 34. During the centrifugal separation process, a film of oil/liquid 26 develops on the inner wall of the return cylinder 36 and cascades down to the main liquid inventory 31 (Figure 1). The return cylinder 36 extends above the top of the curved-arms 34 where there are a number of perforations 38, preferably about 12.7 mm (1/2 inch) in diameter, and a retaining lip 40 at an open top 42 of the separator 30, which are used to improve the liquid removal capabilities of the separator 30 at high gas and liquid flows, and especially where slug conditions can exist. Various perforation geometries may be employed. The wet gas 28 exits the open top 42 of the primary separator(s) 30 into a substantially open interstage region 44 which is used to distribute the wet gas 28 more evenly prior to its entering the secondary cyclone(s) 50. This interstage region 44 also permits liquid droplets to fall out by gravity when the wet gas flow 28 is below the droplet entrainment threshold. To ensure that the export gas 20 is as dry as possible, a required spacing distance 46 (Figure 5) is maintained between the primary separators 30 and the secondary separators 50, preferably at approximately 1.2 m (4 feet).

A separation distance 48 is also maintained between the top of the multi-layered curved-arms 34 and the open top 42 of the primary separator 30, and preferably ranges from approximately 380 mm to 460 mm (15 to 18 inches). Liquid removal capacity can be increased by extending this distance.

As the two-phase wellhead fluid mixture 12 flows out through the curved-arms 34, separation occurs as the heavier oil/liquid droplets 26 migrate to the outer radius of the curved-arms 34 and the less dense wet gas 28 migrates to the inner radius of the curved-arms 34. Separation in the curved-arms 34 allows for an oil/liquid film 26 to be cleanly discharged onto the inner diameter of the return cylinder 36. The retaining lip 40 and perforations 38 are important at high wellhead fluids mixture 12 flows because the retaining lip 40 restricts the growth of the oil/liquid film 26 upwardly while the perforations 38 remove the separated oil/liquid 26 from the inside of the return cylinder 34 allowing it to return by gravity along the outside of the return cylinder 36 to become a part of the oil/liquid inventory 31. After flowing through the primary separator 30, the majority of the separated oil/liquid 26 spirals downwards on the inner diameter of the return cylinder 36 and combines with the liquid inventory 31 in the pressure vessel 14. The wet gas 28 and any remaining entrained oil/liquid droplets 29 enter the secondary separator 50 where the oil/liquid 29 is centrifugally separated from the wet gas 28. The separated oil/liquid 29 is returned to form a part of the liquid inventory 31 via the drain tube 52 and the liquid-free vapour or export gas 20 exits the pressure vessel 14 as shown in Figure 1.

The primary separator 30 has several advantages. The first is that the majority of the separation processes occur at the curved-arms 34. This makes the process inherently capable of accommodating a wide range of flow and level conditions and minimizes the potential for gas entrainment and resultant swelling in the inventory 31 of the pressure vessel 14. Another advantage is that the relatively large flow passages of the curved-arms 34 essentially eliminate the risk of pluggage since there are no narrow gaps which could attract deposits. The result is a low-pressure drop, high performance primary separator 30 that will have a long life of maintenance-free service.

The secondary separator 50 also operates on the principle of centrifugal separation. The wet gas 28 enters the secondary separator 50 through tangential inlet vanes 54 at the bottom of the secondary separator 50 which impart a centrifugal motion to the wet gas 28. Any liquid remaining in the wet gas 28 is then forced to the inner wall of the secondary separator 50 where it is separated by secondary skimmer slots 56, exits through a secondary outlet 57, and spills into a secondary compartment 58 (Figure 1). The secondary separator(s) 50 would typically be inserted through and supported by a plate 60, to which would also be connected drain tubes 52. Bypass holes 62 are placed in a top plate 64 of a tertiary compartment 59 to allow gas bypassing through the secondary skimmer slots 56 to exit the tertiary compartment 59 and enhance the skimming action. The separated oil/liquid 29 then drains via the drain tube 52 back into the lower portion of the pressure vessel 14 and becomes a part of the main pressure vessel's liquid inventory 31. The drain tube 52 isolates the returning separated oil/liquid 29 from the upflowing wet gas flow 28 and avoids the re-entrainment of the separated oil/liquid 29 by the upflowing wet gas 28.

The centrifugal force cyclone, secondary separator 50 has an inherent advantage over scrubber or mesh type dryers. Both scrubber and mesh type dryers are limited in flow capacity by the droplet entrainment threshold, beyond which liquid droplets are entrained with the vapour and are carried therewith. The centrifugal force cyclone, secondary separator 50, on the other hand, can efficiently operate at vapour fluxes typically two to three times higher than the droplet entrainment threshold.

Figure 3 illustrates a second embodiment of the present invention which comprises a single pair, centrifugal, gas/oil separator apparatus 70, for subsea applications. In this embodiment, the pressure vessel 14 is supported and partially contained by a pipe or conduit 72 partially embedded within a seabed 74. The pressure vessel 14, as shown in Figure 4, includes a radial, side wellhead fluid inlet 76 for providing the wellhead fluids 12 into the vessel 14 as well as an oil/liquid export outlet 78 for conveying the separated oil or liquids 24 out of the pressure vessel 14 and a gas export outlet 78 for conveying the separated gases 20 from the pressure vessel 14. The height 82 between the export gas outlet

80 and the top of the conduit 72 is preferably approximately 1.5 m (5 feet). The height 84 of the return cylinder 36 is dependent on inventory and level control requirements.

Figure 6 illustrates the performance characteristics of a single-module centrifugal separator pair in a steam/water environment. The results from a steam/water test at 880 psia test pressure were used for conservatively estimating gas/oil separator performance. These estimates suggest that a single centrifugal separator pair (one primary and one secondary separator) can effectively separate over 43,000 barrels per day (BPD) of oil and over 20 million standard cubic feet per day (20,000,000 SCFD or 20 MMSCFD) of gas for high pressure (approximately 100 psia) applications and over 34,000 BPD oil and 15 MMDCFD gas for low pressure (approximately 250 psia) applications. The peak production for a typical water driven 10-well field is around 25,000 BPD and 14 MMSCFD.

The advantageous features of the present systems are noted and summarized below:

1 One unique feature is the use of centrifugal-type separators for both the primary and secondary stages of separation. Other separator arrangements typically rely on gravity or inertial separation, which is limited in flow capacity by the droplet entrainment threshold beyond which liquid droplets are entrained with the vapour and are carried downstream. In contrast, the secondary separator of the present system is a centrifugal-type separator which can efficiently operate at vapour fluxes significantly higher than the entrainment threshold.

2 The compactness of the present systems is also advantageous. The separation envelope needed for a single-module, centrifugal gas/oil separator arrangement is approximately 1.2 m (4 feet) long by 0.6 m (2 feet) in diameter. Additional drum or pressure vessel 14 volume may be required to satisfy other system parameters such as inventory demands and liquid level control requirements. A pump 86 for pumping separated liquids and a provision for removing sand 90 from the liquid inventory 31, such as a sand separator or pump schematically indicated at 88, may be incorporated into the gas/oil separator arrangement 70 for certain applications as shown in Figure 3.

3 Another feature of the present system is the manner in which the centrifugal forces are generated in the primary separator 30. The centrifugal force develops as the mixture turns 90° out of the riser tube 32 and flows out through the curved-arms 34. This feature allows the two-phase wellhead fluids mixture 12 to enter the pressure vessel 14 through either a lower axial inlet to the riser tube 32 (Figure 1) or through a side, radial inlet to the riser tube 32 (Figure 3) providing design flexibility for introducing the wellhead fluids 12 into the gas/oil separator arrangements 10, 70. Other known separator designs used for gas/oil applications rely on a radial or tangential inlet into the primary separator to create the centrifugal forces.

The compact, high-efficiency, gas/oil separator arrangements 10, 70 offer several advantages when compared to the known designs. These advantages include a high vapour capacity, a compact arrangement, and maintenance-free characteristics of the separation equipment.

Another advantage is that the primary and secondary centrifugal separators 30, 50 have no moving parts and no small passages. This eliminates the potential for hardware pluggage and provides for reliable, long-term, maintenance-free operation, which is extremely beneficial for subsea gas/oil separation applications where accessing the equipment for unplanned maintenance has proven to be very costly.

The compactness of the present systems provides economical advantages because of the reduced capital to initially fabricate the unit and because of reduced space requirements and/or lifting capacity required to install the equipment topside or subsea.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

Claims

1. Apparatus for the separation of oil and gas phases contained in wellhead fluids obtained from hydrocarbon production systems, the apparatus comprising:

   a pressure vessel (14) having a wellhead fluid inlet (16) for entry of the wellhead fluids (12), a gas export outlet (18) for exit of export gas (20) separated therefrom and a liquid export outlet (22) for exit of liquid (24) separated therefrom;
   first centrifugal separation means (30) in the pressure vessel (14) for centrifugally separating oil from the wellhead fluids (12) to produce a wet gas containing some remaining oil; and
   second centrifugal separation means (50) in the pressure vessel (14) for further centrifugally separating substantially all of the remaining oil from the wet gas to produce the export gas (20).

2. Apparatus according to claim 1, wherein the second centrifugal separation means (50) is located above the first centrifugal separation means (30) within the pressure vessel (14).

3. Apparatus according to claim 2, wherein the gas

export outlet (18) is located near the second centrifugal separation means (50).

4. Apparatus according to claim 1, claim 2 or claim 3, wherein the first centrifugal separation means comprises at least one centrifugal force primary separator (30).

5. Apparatus according to claim 4, wherein the second centrifugal separation means comprises at least one centrifugal force secondary separator (50).

6. Apparatus according to any one of the preceding claims, wherein the first centrifugal separation means (30) includes a riser tube (32) for conveying the wellhead fluids (12).

7. Apparatus according to claim 6, wherein the first centrifugal separation means (30) further includes a return cylinder (36) around the riser tube (32) for carrying a separated liquid.

8. Apparatus according to claim 7, wherein the first centrifugal separation means (30) further includes a plurality of curved-arms (34) near the riser tube (32).

9. Apparatus according to claim 7 or claim 8, wherein the return cylinder (36) has a plurality of perforations (38) therethrough.

10. Apparatus according to any one of the preceding claims, wherein the first centrifugal separation means (30) and the second centrifugal separation means (50) define a substantially open interstage region (46) therebetween.

11. Apparatus according to claim 10, further including support plate and top plate means (60, 64) for partially defining a secondary compartment (58) in fluidic communication with a secondary separator outlet (57) located above the interstage region (46), and a tertiary compartment (59) in fluidic communication with intermediate skimmer slots (56) provided on said secondary separation means (50).

12. Apparatus according to claim 11, wherein the top plate means (64) includes a plurality of holes (62) therein for venting gas from said tertiary compartment (59) to said secondary compartment (58), and the support plate (60) is fluidically connected to a drain tube (52) for draining separated liquid from said tertiary compartment (59) back to a lower portion of the pressure vessel (14).

13. Apparatus according to any one of claims 1 to 10, wherein the secondary centrifugal separation means (50) comprises skimmer slots (56) to permit separated liquid to pass therethrough.

14. Apparatus according to any one of the preceding claims, including means (86) for pumping the wellhead fluids (12) to the first centrifugal separation means (30).

15. Apparatus according to any one of the preceding claims, wherein the wellhead fluid inlet (16) is located at a bottom portion of the pressure vessel (14), and the liquid export outlet (22) is located at an intermediate location on the pressure vessel (14) between the wellhead fluid inlet (16) and the gas export outlet (18).

16. Apparatus according to any one of the preceding claims, wherein both the wellhead fluid inlet (16) and the liquid export outlet (22) are located in the pressure vessel (14) at a side radial inlet and outlet, respectively.

17. A method of separating a wellhead fluid mixture obtained from hydrocarbon production systems containing oil and gas phases into its constituent parts, the method comprising the steps of:

   conveying the wellhead fluid mixture into a pressure vessel (14);
   performing a first centrifugal separation (30) of the oil from the wellhead fluid mixture to produce a wet gas containing some remaining oil; and
   performing a second centrifugal separation (50) of the wet gas to remove substantially all of the remaining oil from the wet gas to produce export gas (20).

18. A method according to claim 17, including conveying the separated export gas (20) from the pressure vessel (14).

19. A method according to claim 17 or claim 18, including conveying the separated oil and remaining oil from the pressure vessel (14).

FIG. 2

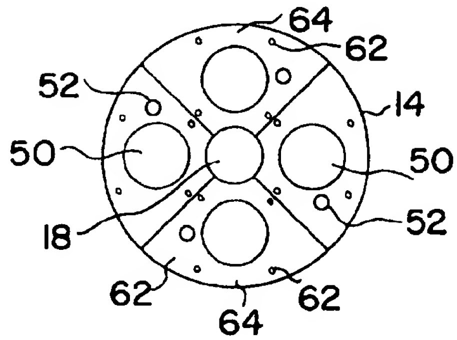
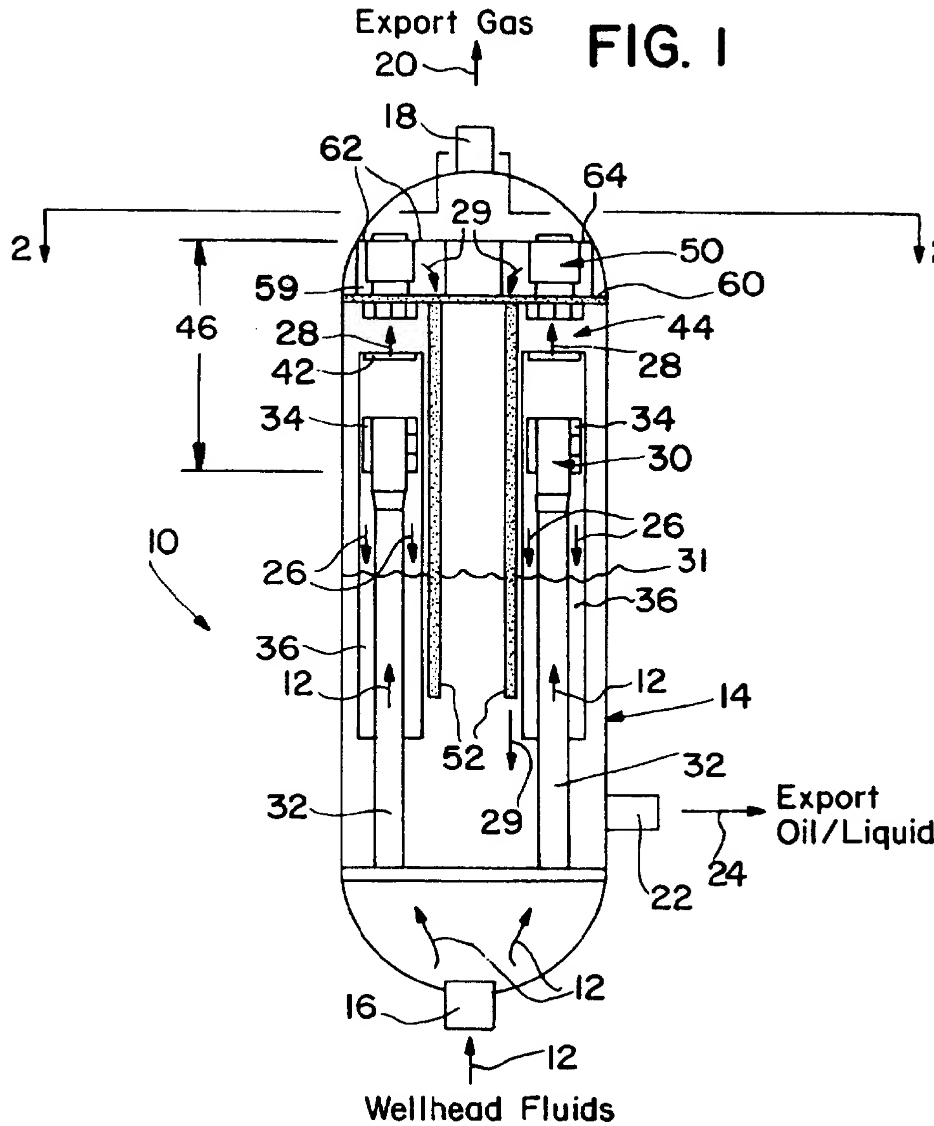

64
62
52
14
50
50
18
52
62
64
62

FIG. 1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18
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60
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42
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26
26
31
36
36
12
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14
52
32
32
29
Export
Oil/Liquid
24
22
12
16
12
Wellhead Fluids

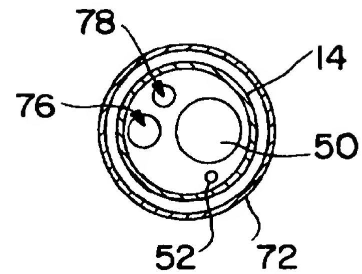
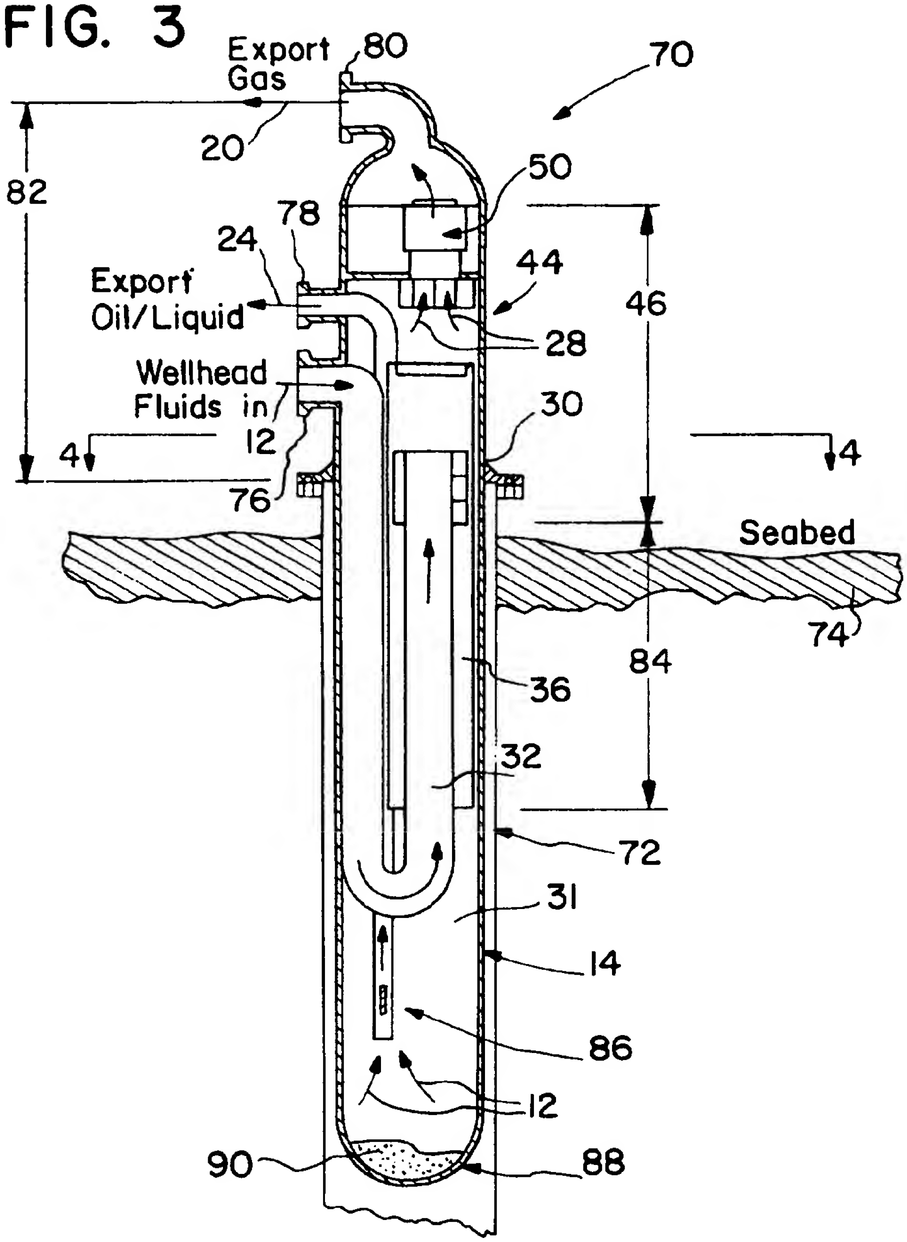

78
76
14
50
52
72

FIG. 4

FIG. 3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Seabed
74
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36
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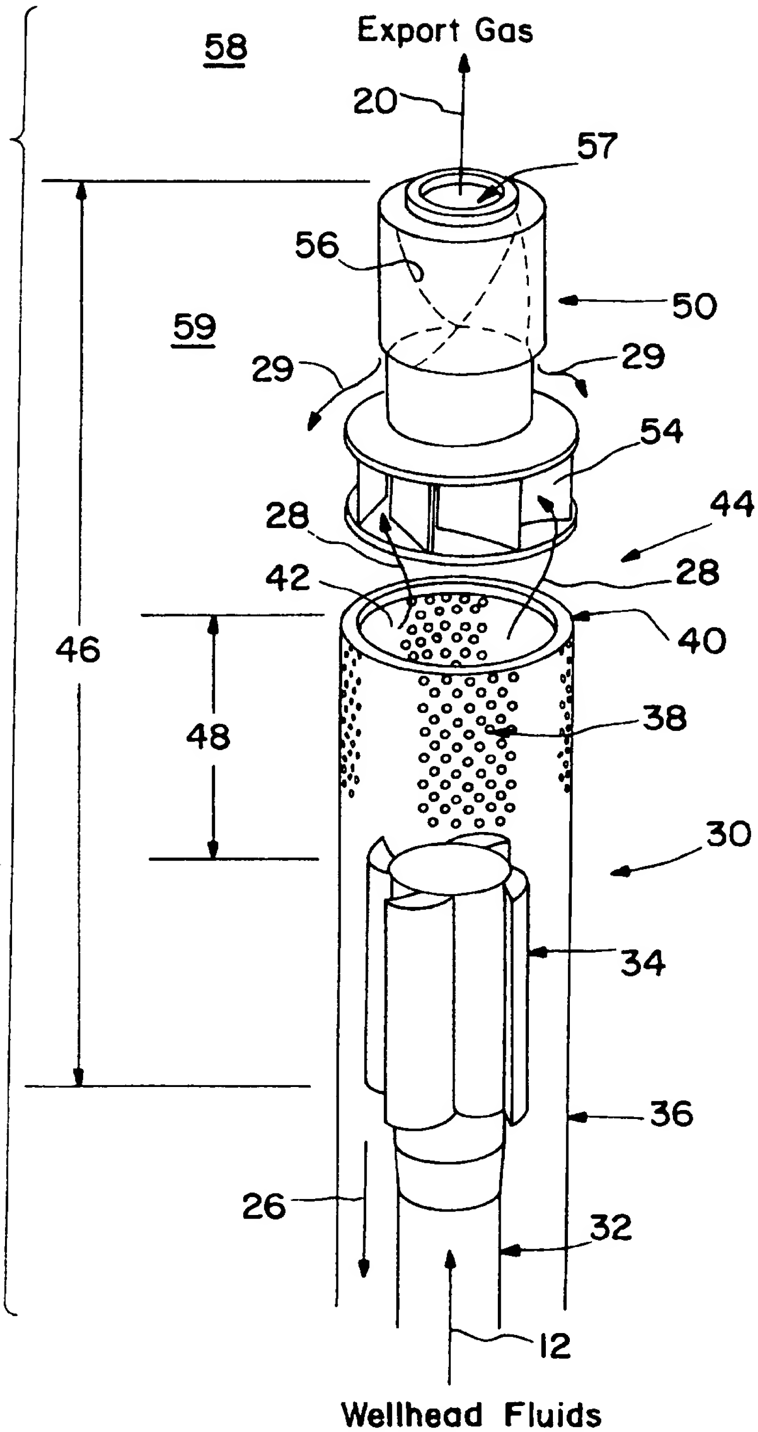
72
31
14
86
12
90
88

FIG. 5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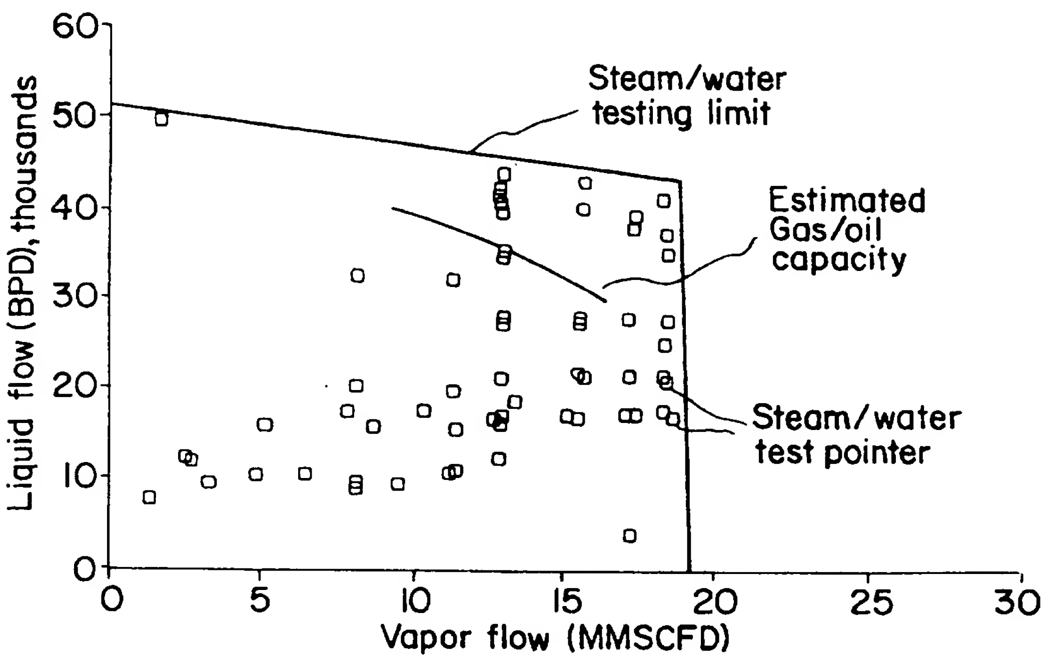
Wellhead Fluids

FIG. 6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0
5
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15
20
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30
Vapor flow (MMSCFD)
Steam/water
testing limit
Estimated
Gas/oil
capacity
Steam/water
test pointer

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(71) Applicant: **THE BABCOCK & WILCOX COMPANY**
New Orleans, Louisiana 70160-0035 (US)

(72) Inventors:
- **Prueter, William Paul**
Alliance, Ohio 44601 (US)
- **Birmingham, Daniel P.**
North Canton, Ohio 44721 (US)
- **Reed, Matthew J.**
Canton, Ohio 44709 (US)

(74) Representative: **Pilch, Adam John Michael et al**
D. YOUNG & CO.,
21 New Fetter Lane
London EC4A 1DA (GB)

(54) **Separation of oil and gas phases in wellhead fluids**

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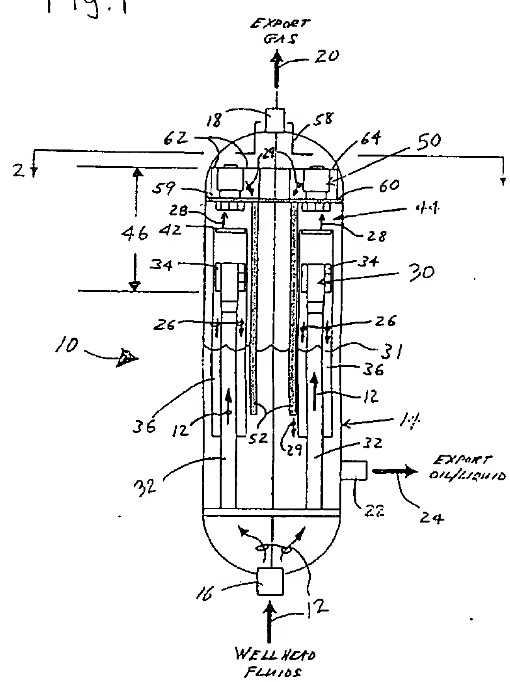
Fig. 1



EP 0 711 903 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 95 30 7876

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	US 2 037 426 A (R.S. MCKEEVER) 14 April 1936 * the whole document *	1-5,10, 17-19 6-9, 11-13,15	E21B43/36 E21B43/34 B01D19/00
D,Y	US 4 648 890 A (J.H.KIDWELL ET AL.) 10 March 1987 * claim 1; figures 1-8 *	6-9,15	
D,Y	US 3 324 634 A (M.A. BRAHLER ET AL.) 13 June 1967 * column 2, line 15-21; claim 1; figures 1-7 *	11-13	
X	US 2 256 524 A (J.F. MCKELVEY) 23 September 1941 * the whole document *	1-5,10, 16-19	
X	US 2 533 977 A (E.M. VAN DORNICK) 12 December 1950 * column 3, line 21-60; figures 1-9 *	1,13, 17-19	TECHNICAL FIELDS SEARCHED (Int.Cl.6) E21B B01D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25 June 1997	Grentzius, W

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